1 A and 120 mA Thin-Film Multijunction Thermal Converters

Hector Laiz (INTI)

Thomas Wunsch (Sandia)

Joseph Kinard (NIST)

Thomas Lipe (NIST)

INTI

NIST

ACDC

Contents

- Background

- Project goals

- Present status of project

- Future plans

- Conclusions

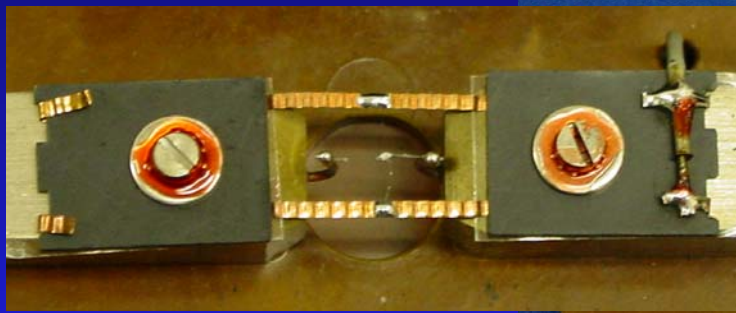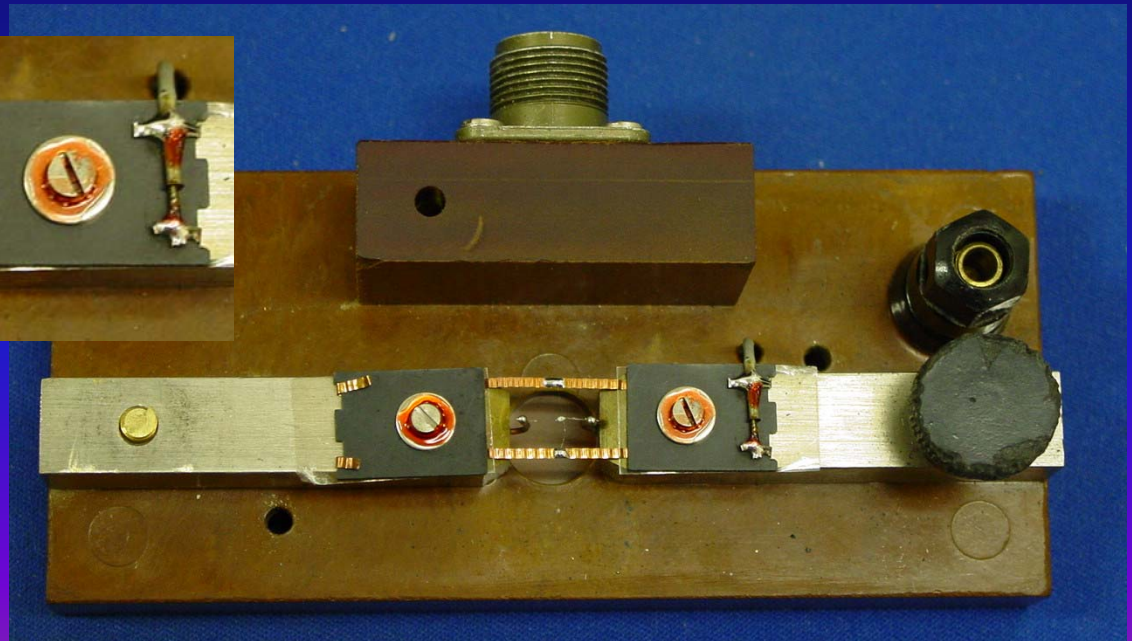# *Background*

- NIST has relied on high-current thermoelements for current measurements. Other NMIs rely on current shunt/TE combinations

Weston TE

Background

- Thin-film technology will enable us to make high-current thermal converters with much better performance than either the Weston TEs or shunt/TE combinations

- Benefits:
  - Higher accuracy
  - Lower cost/Mass production

Background

- The NIST standards are old (c.1960), and many have been lost
  - Overloading
  - Random age-related failures
  - Cannot be replaced or repaired
- **NIST is in critical need of new, high-performance standards**

Project Goal

- To develop new high-current thermoelements for measurement of ac currents up to 10 A

Project Goal

- Develop 1 A and 120 mA TEs

- Use in parallel combinations to scale to 10 A

MJTC combinations to scale from 100 mA to 10 A			
1 MJTC	2 in parallel	4 in parallel	8 in parallel
120 mA	240 mA	480 mA	1 A
1 A	2 A	4 A	10 A

Why not shunts?

- Lower voltage drop across heater
  - Reduces temperature-dependent errors
- Smaller skin effect
  - Reduces high-frequency error
- High impedance to ground
- Larger output emfs
  - Scaling accuracy

1 A MJTC Design Parameters

- 0.1 V drop across heater

  – 100 mW heater power

  – 0.1 Ω heater resistance

- Requirements

  – New chip design

  – New low-resistance heater material

1 A MJTC Design Parameters

$$\beta_S = \frac{1}{S}\frac{\partial S}{\partial T} \approx \frac{1}{\alpha_{A/B}}\frac{\partial \alpha_{A/B}}{\partial T} - \frac{1}{G_T}\frac{\partial G_T}{\partial T} - \alpha$$

Temperature coefficient of Seebeck coefficient   Temperature coefficient of thermal conductance   Temperature coefficient of heater resistance
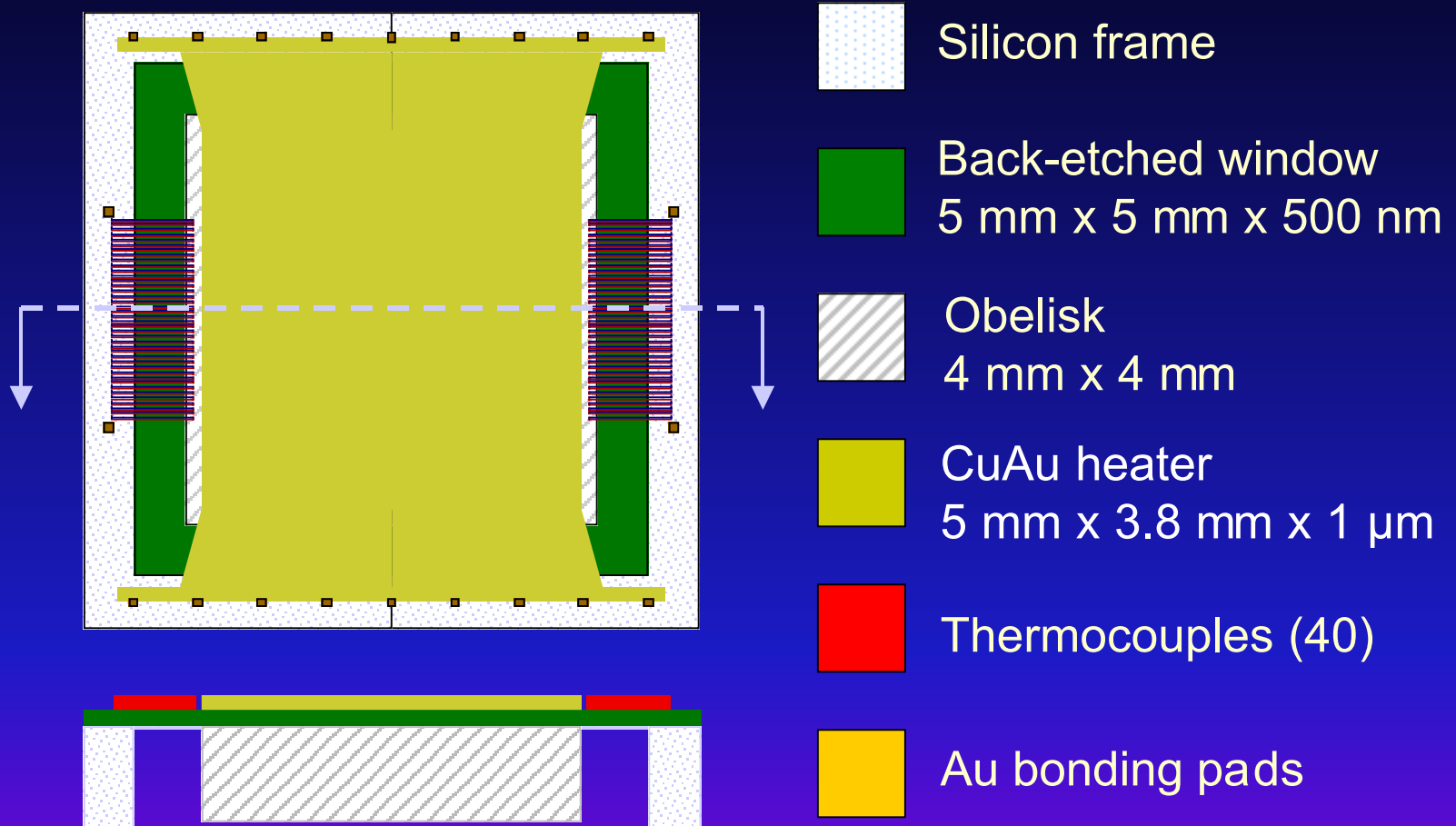
- Use CuAu heater to optimize the temperature coefficient of the sensitivity
  - β_s = +3.2 x 10^{-3} K^{-1} (gold)
  - β_s = -6.0 x 10^{-4} K^{-1} (Evanohm)
  - **β_s = -2.5 x 10^{-4} K^{-1} (copper-gold)**

1 A MJTC Chip Design

Silicon frame

Back-etched window
5 mm x 5 mm x 500 nm

Obelisk
4 mm x 4 mm

CuAu heater
5 mm x 3.8 mm x 1 μm

Thermocouples (40)

Au bonding pads

1 A MJTC Thermal Simulation

Ambient + 10 K
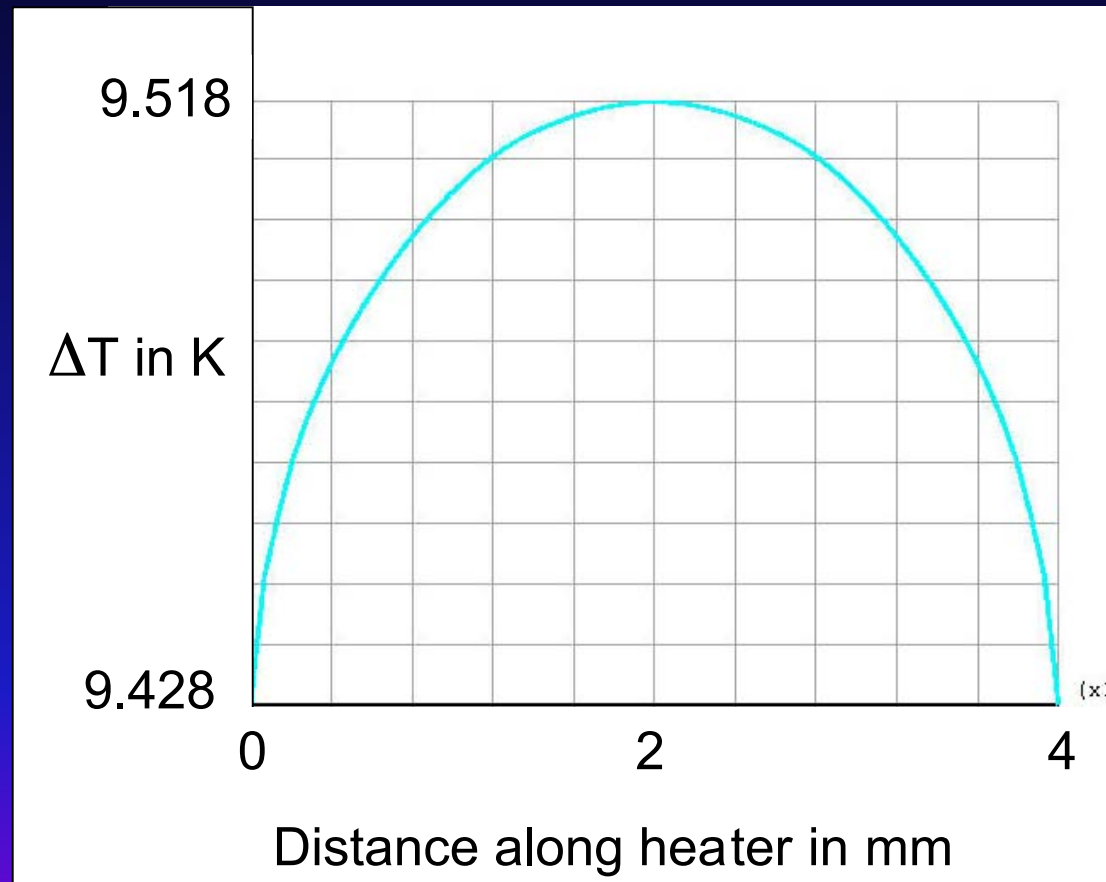
Ambient
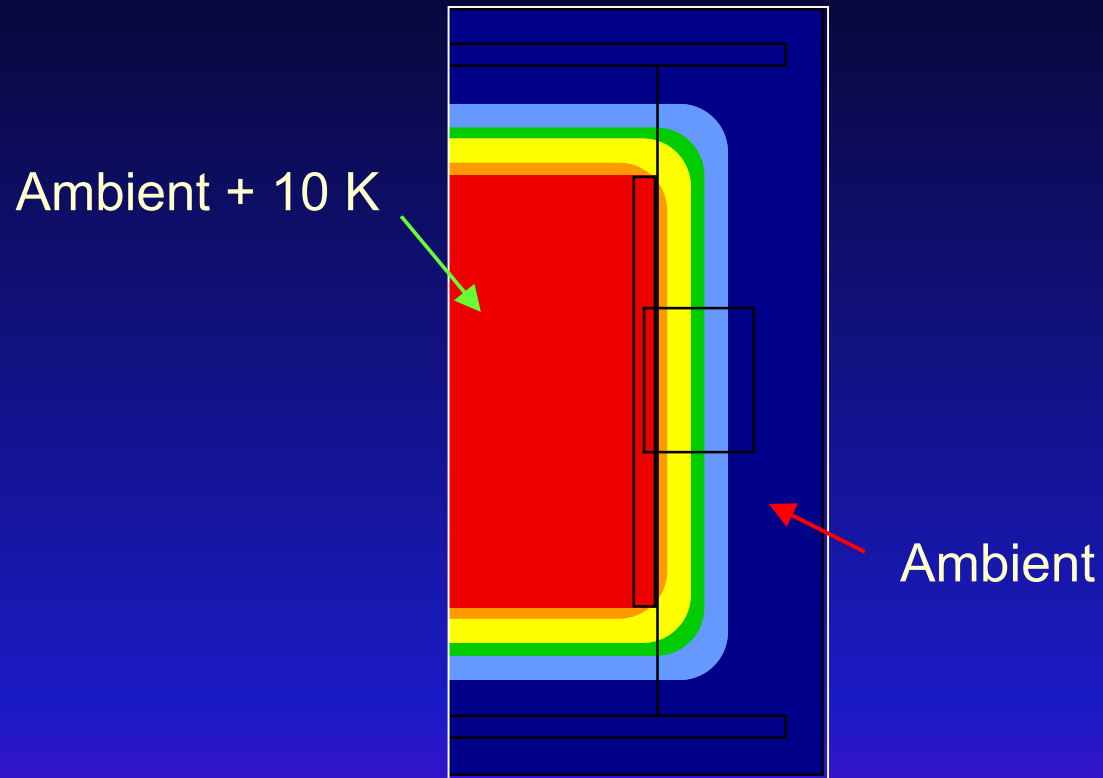
Temperature distribution on one-half the 1 A MJTC

1 A MJTC Temperature Profile

1 A MJTC Simulation Results

- Most heat is conducted through the heater
  - High conductivity
  - Large cross section
- Small temperature gradient
  - Reduced Thomson errors
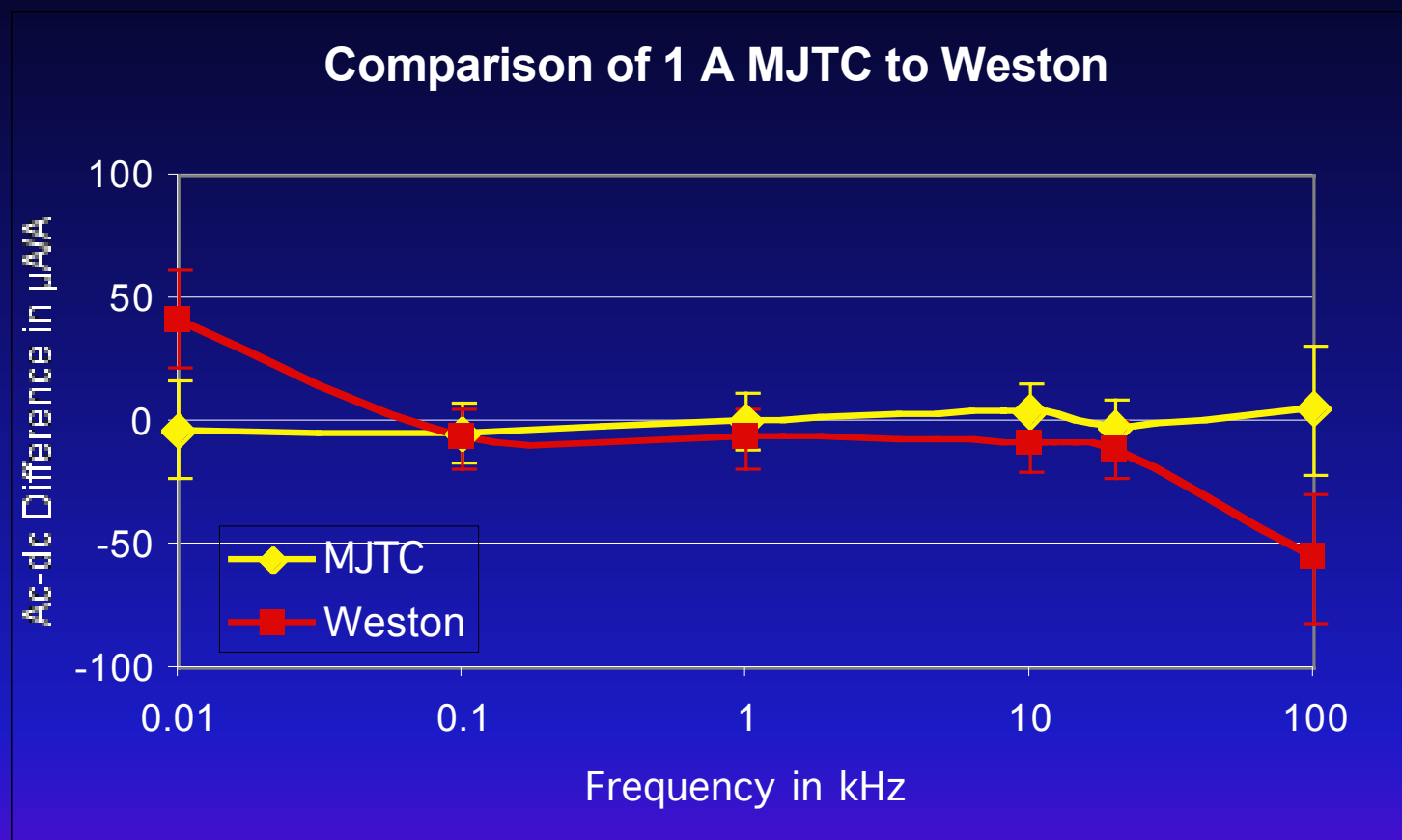
1 A MJTC Simulation Results

- High thermal conductance of the Si frame
  - Reduced Peltier errors
- Thermocouple banks disconnected
  - External connection reduces high-frequency errors

1 A MJTC Measurements

Comparison of 1 A MJTC to Weston

Time constant: 0.5 s
Dc reversal: < 10 µA/A

120 mA MJTC Chip Design

- Test: 1 A design, Evanohm heater
  - 833 mV drop for 100 mW power
  - Increased ac-dc difference from leakage capacitance
- Design goals:
  - 100 mV drop at 120 mA:12 mW power
  - Heater resistance of 0.83 Ω
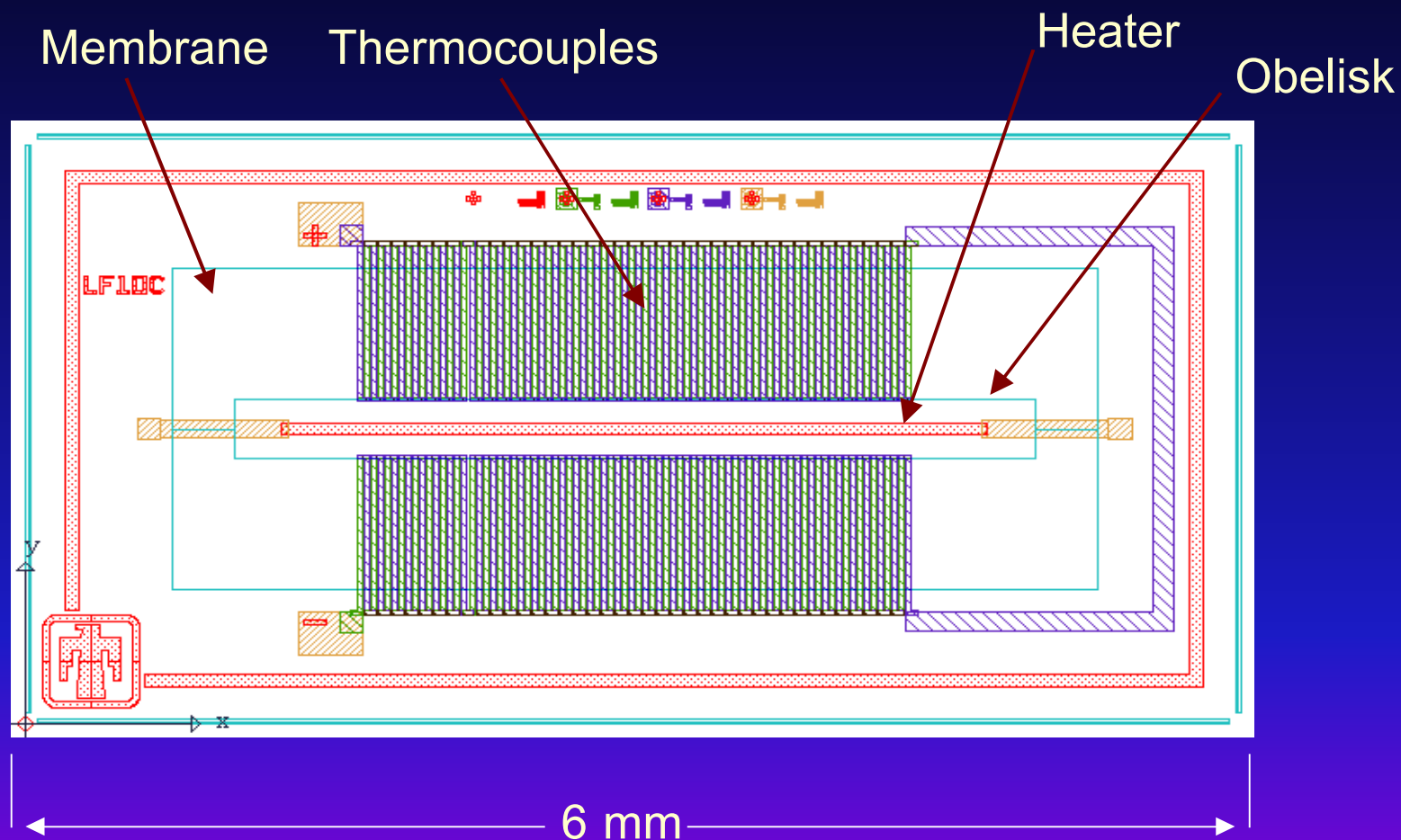
120 mA Chip Design

- Propose to use 400 Ω TVC design with these modifications:

    – Disconnect thermocouple banks

    - Reduces high frequency errors

    – Place thermocouples 10 µm from obelisk

    - Reduces capacitive coupling

    – CuAu heater
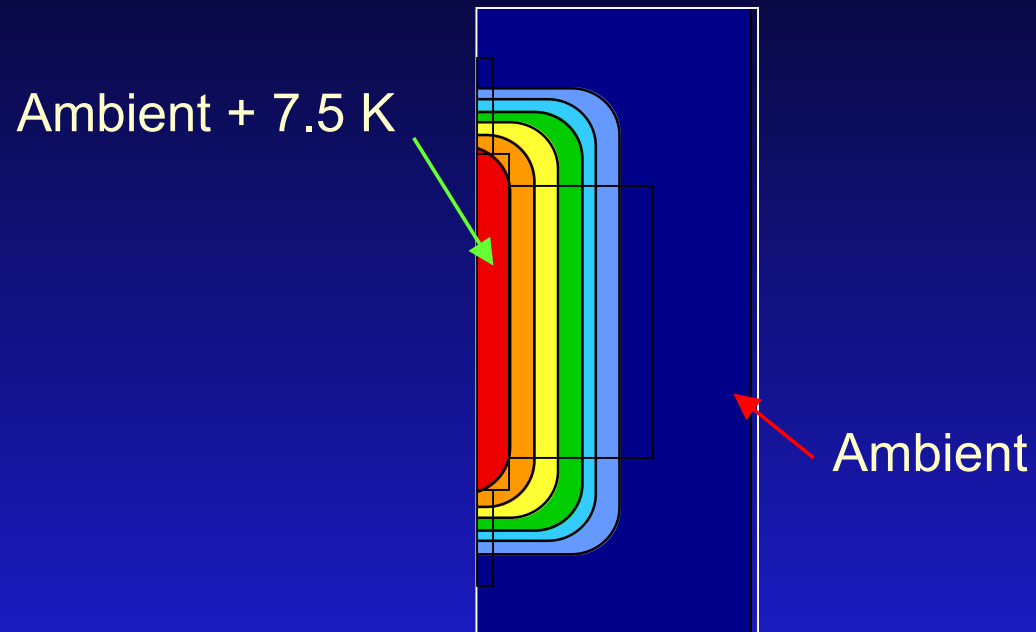
    - 3 000 µm x 220 µm x 1 µm

120 mA MJTC Chip Design

Membrane Thermocouples Heater Obelisk

6 mm

120 mA MJTC Thermal Simulation

Ambient + 7.5 K

Ambient

Temperature distribution on one-half the 120 mA MJTC

Future Plans

- Fabricate MJTCs at NIST (Boulder, CO)
  - We need many more chips than we have
  - We need better communication with the fabrication facility
- Build high-current (10 A) multiconverter modules

Conclusions

- 1 A MJTCs
  - Designed
  - Modeled
  - Fabricated (a few)
  - Measured
    - Ac-dc Differences shown to be extremely small from 10 Hz to 100 kHz
    - Measurements agree with simulation
  - Presently addressing fabrication issues

Conclusions

- 120 mA MJTCs
  - Designed
  - Modeled
  - Hope to begin fabrication soon